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UNITED STATES PATENT APPLICATION

FOR

METHOD AND APPARATUS FOR  
STORING POSITION OFFSET INFORMATION  
ON A HARD DRIVE ASSEMBLY CYLINDER

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BACKGROUND OF THE INVENTION

The present application is a continuation-in-part application of U.S. Patent No. 08/641,685 entitled "Method and Apparatus for Providing Read and Write Skew Offset Information for a Magneto-Resistive Head" filed May 1, 1996.

1. Field of the Invention

The present invention relates in general to disk storage systems and more particularly, to a method and apparatus for providing and storing skew offset information for aligning the read element of a magneto-resistive (MR) head with the centerline of written data during a read operation.

2. Description of the Related Art

Disk drives are magnetic recording devices used for the storage of information. The information is recorded on concentric tracks on either surface of one or more magnetic recording disks. The disks are rotatably mounted to a spin motor and information is accessed by means of read/write heads that are mounted to actuator arms which are rotated by a voice coil motor. The voice coil motor is excited with a current to rotate the actuator and move the heads. The read/write heads must be accurately aligned with the storage tracks on the disk to ensure proper reading and writing of information.

To accurately write and read data, it is desirable to maintain the head on the center of the track. To assist in

controlling the position of the head, each sector of the disk typically contains a number of servo bits accurately located relative to the centerline of the track. The signals produced by the servo bits are typically demodulated into position offset  
5 signals which are used to determine the position of the head relative to the track, and to move the actuator arm if the head is not located on the track centerline.

There has been developed a dual element transducer which includes a single write element and a separate read element  
10 which is constructed from a magneto-resistive material. Such dual element transducers are commonly referred to as magneto-resistive (MR) heads. Because of manufacturing tolerances, the separate magneto-resistive read element may be off-center or skewed from the write element of the head. Therefore, if data  
15 is written off the center of the track, to read the data, the servo system must move the head slightly off-center so that the read element is centered with the written data.

Additionally, while the read and write elements may be aligned when the head is positioned over a particular track,  
20 when the head is moved to another track, the read element may no longer be aligned with the write element. For example, as shown in Figures 1A and 1B, when the head is positioned over a track along the outer diameter of the disk, the centers of the read and write elements (R and W respectively) are aligned.  
25 However, as shown in Figures 2A and 2B, when the head is positioned over a track along the inner diameter of the disk,

the centers of the read R and write W elements are no longer aligned. The servo system must move the head slightly off-center, so that the read element R is centered with the written data. The routine of moving an MR head during a read operation  
5 is commonly referred to as micro-jogging.

It also has been determined that the skew offset information for an MR head located over the inner tracks of a disk is different from that of an MR head located over the outer tracks of a disk. In addition, such MR head skew offset information is typically non-  
10 linear, and it also generally varies greatly between heads.

Accordingly, there is a need in the technology for a method and apparatus for providing skew offset information used in the alignment of a magneto resistive head, so that a read element of an MR head may be aligned with the centerline of written data  
15 during a read operation.

In non-MR servo systems, the stored parameters are read during a power up sequence so as to optimize the performance for the particular drive. In systems utilizing an MR head, the data written on the dedicated tracks may not be centered exactly on  
20 the tracks because the read and write heads are offset. As a result, when the system attempts to read the written data, additional time is required to locate the centerline of the written data. Alternatively, several attempts to read the written data may be required before successfully acquiring the  
25 written data. To compound this problem, the associated parameters are typically written on the outermost tracks of the

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disk where the largest offset between the read and write elements generally occurs.

Accordingly, there is also a need in the technology for an apparatus and method of storing system parameters so that hard  
5 drive assemblies utilizing MR heads may efficiently retrieve the stored information.

BRIEF SUMMARY OF THE INVENTION

A method and apparatus for storing position offset information not used for aligning the read element of an MR head with the centerline of written data, during a read operation. The skew or  
5 offset between the read and the write elements on a read head is first calibrated. The offset information then stored on one or more dedicated tracks of the disk. To accomplish this, the write element is aligned with the centerline of the dedicated track. The position offset information is then written in the data field of  
10 the dedicated track. During the power-on process, the read element is aligned with the centerline of the dedicated track and the position offset information may be retrieved by simply reading the information previously stored on the dedicated track.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A illustrates a read/write head positioned over a track along the outer diameter of a disk of the prior art.

Figure 1B is an enlarged view of the read/write head of Figure 1A, illustrating the relative positions of a read element that is aligned with a write element on a typical magneto resistive head, in the prior art.

Figure 2A illustrates a read/write head positioned over a track along the inner diameter of a disk of the prior art.

Figure 2B is an enlarged view of the read/write head of Figure 2A, illustrating the relative positions of a read element that is misaligned with the write element on a typical magneto resistive head, in the prior art.

Figure 3 illustrates a hard disk drive which utilizes the method of the present invention.

Figure 4 is a block diagram of an integrated circuit read channel in accordance with the present invention.

Figure 5 illustrates a data sector of a disk.

Figure 6A is an enlarged view of a portion of the data sector of Figure 5, illustrating the calibration burst utilized in the method of the present invention.

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Figure 6B is a graph illustrating the magnitude of the calibration burst with respect to the position of the read element of a magneto resistive head.

Figure 7A illustrates a timing diagram of the servo burst sequence used in calibrating the offset values between the read and write elements in a magneto resistive head, in accordance with the teachings of the present invention.

Figure 7B is a flowchart illustrating the offset calibration technique of the present invention.

Figure 8 illustrates a timing diagram of the servo burst sequence during normal operation of a hard disk drive, upon implementing offset calibration, in accordance with the teachings of the present invention.

Figure 9A is an enlarged view of the magneto resistive head of Figure 5, illustrating the relative position of the write element that is aligned with a track centerline during the writing of system parameters on the track.

Figure 9B is a flowchart illustrating the system parameter storage process of the present invention.

Figure 10A is an enlarged view of the magneto resistive head of Figure 5, illustrating the relative position of the read element that is aligned with a track centerline during the reading of system parameters located on the track.

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Figure 10B is a flowchart illustrating the system parameter retrieval process of the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings more particularly by reference numbers, Figure 3 shows a hard disk drive 100. The disk drive 100 includes a disk 102 that is rotated by a spin motor 104.

5 The spin motor 104 is mounted to a base plate 106. Also mounted to the base plate 106 is an actuator arm assembly 108. The actuator arm assembly 108 includes a number of heads 110 mounted to corresponding flexure arms 112. The flexure arms 112 are attached to an actuator arm 114 that can rotate about a bearing  
10 assembly 116. The assembly 108 also contains a voice coil motor 118 which moves the heads 110 relative to the disk 102. There is typically a single head for each disk surface. The spin motor 104, voice coil motor 118 and the heads 110 are coupled to a number of electronic circuits 120 mounted to a printed circuit  
15 board 122. In the following discussion, only one head 110 is referenced. The electronic circuits 120 typically include a read channel chip, a microprocessor-based controller and a random access memory (RAM) device.

Figure 4 is a block diagram of one of the electronic circuits  
20 120 of Figure 3. The electronic circuit 120 includes a preamplifier 122 which is coupled to a read/write (R/W) channel circuit 124. The read/write channel circuit 124 includes a R/W Automatic Gain Control (AGC), a filter circuit 126, a fullwave rectifier 128 and a peak detector 130. The electronic circuit 120 further comprises a  
25 microprocessor-based servo controller 132 which includes an analog-to-digital converter (ADC) 134, a digital signal processor 136 and

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a burst sequencer and timing circuit 138. In addition, the electronic circuit 120 includes a random access memory (RAM) device 140.

The electronic circuit 120 is coupled to one of the  
5 magnetic heads 110 which senses the magnetic field of a magnetic disk 102. When reading the servo information located in the servo field region 10 on the disk 102, the head 110 generates a read signal that corresponds to the magnetic field of the disk 102. The read signal is first amplified by the preamplifier  
10 122, and then provided to the R/W channel circuit 124. The AGC data included in the read signal is provided to the R/W AGC and filter circuit 126. The AGC data provided by the read signal is monitored by the R/W AGC circuit portion of circuit 126 and the read signal is then filtered by the filter circuit located in  
15 the circuit 126. The fullwave rectifier 138 rectifies the read signal and provides the rectified read signal to the peak detector 140. In response, the peak detector 140 detects the amplitude of the read signal. The read signal is then provided to the ADC 144 which provides digitized samples of the analog  
20 read signal. The digitized signal is then provided to a digital signal processor 146 which generates the position offset signals based on the servo information read by the head 110, as discussed in detail in the following sections. The values representing the position offset signals are stored in memory  
25 140. The bursts sequencer and timing circuit 138 provide the timing required for the aforementioned processes.

As shown in Figure 5, data is typically stored within sectors of radially concentric tracks located across the disk 102. A typical sector will have an automatic gain control (AGC) field 150, a synchronization (sync) field 152, a gray code field 154 that identifies the track, an identification (ID) field 156 that defines the sector, a servo field 158 which includes a number of servo bits A, B, C, D, a data field 160 which contains the data, and an error correction code field 162. The electronic circuits 120 utilize the servo bits A, B, C and D to maintain the heads 110 on the centerline CL of the track. If the heads 110 are off-center, the electronic circuits 120 will generate a position offset signal which has a voltage amplitude that varies with the distance that the heads 110 are off-set from the track centerline.

The heads 110 can magnetize and sense the magnetic field of the disk 102. In one embodiment, each head 110 has a single write element 164 and a separate read element 166 as shown in Figure 5. The read element 166 is preferably constructed from a magneto-resistive material which changes resistance in proportion to the intensity of an external magnetic field. The read element 166 is sometimes off-set from the write element 164 because of the tolerances associated with the manufacturing process of the head. Additionally, the center of the read element 166 may be offset from the center of the write element 164 because of the skew angle of the head 110 with respect to the track on the disk 102. If the read element 166 is aligned with the center CL of the track, and the write element 164 is

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off-set from the read element 166, the data will be written off-center from the center CL of the track. To properly read the data, the read element 164 must be moved over to the off-center location of the written data.

5 Figure 6A is an enlarged view of a portion of the data sector of Figure 5, illustrating the calibration burst E utilized in the method of the present invention. In one embodiment, the calibration burst E is written in the data field 160 of every sector on a predetermined number of tracks of the disk 102. For example, the calibration burst E may be written only on every fourth track. The number of tracks on which the calibration burst E are written may be determined by calibration accuracy requirements.

15 The servo field 158 in each sector contains a number of servo bits designated A, B, C and D. The boundary formed by the A and B servo bits defines a track CL of the disk 102. The center of the C servo bit is aligned with the center CL of the track. The D servo bit is offset 180° from the position of the C servo bit. The servo bits A and B are used to center the read element with the centerline CL of the dedicated track where the value of A-B corresponds to the off-track position of the head 110 if A-B is a non-zero value. This is accomplished by detecting the amplitude of the servo bursts provided by servo bits A, B, C and D using the read element 166 of the head 110.

25 If the center of the read element 166 is not aligned with the center of the write element 164 (and thus, the center of the

written data), then the servo controller 132 will generate a position offset signal using the technique of the present invention, to move the head 110 so that alignment of the center of the read element 166 with the center of the written data may  
5 be accomplished.

The distance that the head 110 has to be moved in such a situation is determined by the offset between the read element 166 and the write element 164 for a particular track. The technique of the present invention determines the magnitude of  
10 this offset through the use of a calibration burst E. The calibration burst E has a centerline located at a predetermined off-set position from the track centerline CL. The centerline of the calibration burst E is also the center of the write  
15 write element 164 during the calibration process of the disk drive.

Figure 6B is a graph illustrating the magnitude of the calibration burst E with respect to the position of the read element 164 of a magneto resistive head. Upon writing the  
20 calibration burst E in the required servo sectors, the servo controller 132 (Figure 4) performs a seek routine by moving the head 110 from track center to track center. The profile of the calibration burst E with respect to the center CL of each track is then obtained by sampling the amplitude of the calibration  
25 burst E over the width of the track. This is done by micro-jogging the head 110 in increments, from a position that is -50%

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from the center of the track to a position that is +50% from the center of the track, and reading the amplitude of the calibration burst E. This routine is repeated for all servo sectors in which a calibration burst E has been written. The  
5 position value d corresponding to the peak value of the calibration burst E obtained during the microjogging process represents the offset value between the read and write elements 164 and 166, at a particular track location. Upon obtaining the offset value, the servo controller 132 will generate a  
10 demodulated position offset signal having an amplitude representative of the position offset value.

Figure 7A illustrates a timing diagram of the servo burst sequence used in calibrating the offset values between the read and write elements in a magneto resistive head, in accordance with the  
15 teachings of the present invention. The bursts sequencer and timing circuit 138 in the servo controller 132 controls the timing of a servo gate 170, the timing of cycle 172 of servo bursts A, B, C, D and E, and the discharge cycles 174 for initiating the servo bursts. During offset calibration, servo burst reading or writing  
20 is accomplished during the positive pulses of the servo gate 170. Within a single cycle of the servo gate 170, reading of servo bursts A, B, C and D is initiated at the falling edge of the first discharge pulse 174. Reading of the calibration burst E is initiated at the falling edge of the second discharge pulse 174.  
25 The offset calibration cycles continue until offset calibration for all required tracks is accomplished.

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Figure 7B is a flowchart illustrating the offset calibration process of the present invention. The offset calibration process S180 begins from a start state and proceeds to process step S182, where the read element 166 reads the servo bursts A, B, C, and D upon receiving a control signal (i.e., the falling edge of the discharge pulse 174). The servo information obtained is provided to the servo controller 132, which generates a signal for the voice coil to position the head 110 along the center of a track. The process S180 then proceeds to write the calibration burst E in the required servo sectors, as shown in process step S184.

Next, the process S180 obtains a profile of the calibration burst E with respect to the center CL of each track by sampling the amplitude of the calibration burst E over the width of the track, as shown in process step S186. This is done by first performing a seek to a position that is -50% from the center of the track, and then micro-jogging the head 110 in increments, from a position that is -50% from the center of the track to a position that is +50% from the center of the track, and reading the amplitude of the calibration burst E. This routine is repeated for all servo sectors in which a calibration burst E has been written.

The position value  $d$  corresponding to the peak value of the calibration burst E represents the offset value between the read and write elements 164 and 166, at a particular track location. The position offset signal should be ideally zero when the read element 166 is centered with the written data. If the read element 166 is off-set from the write element 164 the position offset

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signal has some non-zero value when the read element is centered over the written data.

Upon obtaining the offset value, the servo controller 132 will generate a position offset signal having an amplitude  
5 representative of the offset value, as shown in process step S188. The value of the position offset signal corresponding to a particular track and sector is stored in RAM 140 for use during normal operation of the disk drive 100 as shown in process step S190. In one embodiment, the position offset values corresponding  
10 to the track number (as identified by gray code) and the ID number (which provides the identification of the sector number) are stored in a table for later referral. Upon completion of the calibration process, the process S180 terminates.

Figure 8 illustrates a timing diagram of the servo burst  
15 sequence during normal operation of a hard disk drive, after offset calibration has been performed, in accordance with the teachings of the present invention. Upon calibrating the read and write elements 166 and 164 of the head 110, normal operation of the disk drive 100 may proceed. During normal operation of a  
20 calibrated drive, the heads 110 are directly moved to the offset position in accordance with the best reading of the written data during the read operation.

The disk drive 100 typically goes through the routine of generating the position offset values after each "power-on"  
25 sequence of the drive. Alternatively, the position offset values can be generated when the disk drive 100 is initially

assembled and then stored in a non-volatile memory medium such as the disk 102.

In a further aspect of the present invention, the position offset values may also be stored on one or more dedicated tracks 192 on the disk 102 (see Figure 9A). Upon powering on, the read element 166 will be directed by the servo controller 132 (see Figure 4) to the position offset values written on the dedicated track 192. Using the position offset values thus stored, the read element 166 of an MR head may be accurately aligned with the centerline of written data during a read operation.

Figure 9A is an enlarged view of MR head of Figure 5, illustrating the relative position of the write element 164 that is aligned with a track centerline during the writing of system parameters on the track 192. Figure 9B is a flowchart illustrating the system parameter storage process S200 in accordance with the teachings of the present invention. Referring to both Figures 9A and 9B, the process S200 begins from a start state and proceeds to process step S202, where the read element 166 reads the servo bursts A, B, C and D upon receiving a control signal from the servo controller 132. The servo information obtained is provided to the servo controller 132, which generates a signal to the voice coil motor 118 (see Figure 3) to position the write element 164 along the center of a dedicated track 192. The process S200 then proceeds to step S204 to retrieve the offset information that was previously

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obtained using the process S180 (as shown in Figure 7B) and which was stored in memory 140 (Figure 4).

Next, the process S200 advances to process step S206, where the write element 164 is first aligned with the centerline of the dedicated track 192 using the position offset information stored in memory 140. The process S200 then writes the position offset information on the dedicated track 192. Other system parameters, such as the read/write channel parameters, may also then be stored on the dedicated track 192. Note that during the process S200, the read element 166 is off the track centerline while the write element 164 is aligned with the track centerline.

During the power-up process S220, as shown in Figure 10B, the servo controller 132 first directs read element 164 to read the servo bursts A, B, C, D on the dedicated track 192 (step S222). Based on the servo information read, the servo controller 132 directs the voice coil motor 118 (Figure 3) to align the read element 166 with the centerline of the dedicated track 192 (step S224). When aligned, the read element 164 reads all the previously stored position offset values and other system parameters from the dedicated track 192 (step S226). This information may be stored back in the memory 140 for later use. Alternatively, it may be used immediately following the read process for various servo operations. The information thus retrieved may be used during the read operation.

Through the use of the present invention, the skew or position offset information used in the alignment of a read element of an MR head may be provided and stored, so that the read element of an MR head may be accurately aligned with the centerline of written data during a read operation, without any additional calibration.

While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art.